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A REVIEW OF METHODS AND EQUIPMENT FOR THE MEASUREMENT OF RUN-OFF

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A REVIEW OF METHODS AND EQUIPMENT FOR THE MEASUREMENT OF RUN-OFF

BY

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INTRODUCTION

1. Run-off may be defined as that part of the hydrologic cycle when water is present on the earth's surface. This paper is confined to the measurement of it in streams, an essential for accurate assessment of the amount available for use.

2. The measurement of stream flow is difficult. Measurement of water is subject to empirical laws and there is rarely a direct method of checking the accuracy of the work. It is necessary therefore to adopt the best available methods so that a standard of accuracy be attained that will provide reliable results. Past experience has shown that records of run-off, which are not of the highest quality, are more misleading than useful. Emphasis must therefore be placed on accuracy and reliability, every endeavour be made to adopt the best recognized procedures, and every precaution be taken to minimize those errors known to exist.

3. The basic principle of measuring run-off is that of inference, it generally being impracticable to make a direct measurement of the discharge of a stream. The method usually adopted is to make, and record, measurements of the discharge at various stream levels, sufficient to enable the relationship between level and discharge to be established. From this relationship, a rating table, or curve, is prepared giving the flow corresponding to all levels of the stream. This rating table is then applied to the record of river levels, with the result that a continuous record of flows in the stream is obtained. It is necessary therefore to relate the level of the stream to a fixed datum so that consistency of level readings can be obtained. This is usually accomplished by installing a suitable graduated gauge staff in the stream, from which the level of the river can be determined.

4. The relationship between the level of the stream and the discharge is controlled either by the physical characteristics of the stream in the vicinity of the gauge, or by some artificial structure, such as a weir. If this 'Control' changes, then the relationship between discharge and gauge level will also change. It is essential therefore to maintain a constant check on the relationship by a continuous programme of flow measurements.

5. The siting of a gauge station that is, a particular point on a stream where gauge readings are obtained and discharge measurements made to obtain flow records of the stream, involves some serious

considerations. Of these the most important is that there should be at the site that stability of relationship between gauge height and discharge that a 'control' may best provide. Sensitivity of the 'control' is important, if reasonably accurate results are to be obtained. The greater the rate of increase in gauge height in relation to flow, the more accurate the results. A site located in a pool or river section where the velocity is low will provide a satisfactory relationship. Access and cost are obvious, but should be subordinate, considerations.

WATER LEVEL RECORDING

6. Automatic recording by an instrument on a chart or tape is far better than that by the visual reading of a gauge set in the river, since:
(a) the gauging station may be located at the desired site, without regard to the availability of a gauge reader.
(b) A complete record of the behaviour of the river can be obtained. Daily readings, usually limited to one or two per day (except perhaps in the lower reaches of large streams), are insufficient to obtain the true average flow and other information, such as peak flows and times of peaks that are important in flood investigation.
(c) Gauge readers have too often been unreliable.
(d) A gauging station should be regularly visited by a responsible person to obtain flow measurements and to maintain the station in good order. As an automatic recorder requires periodic servicing, these regular visits must be made. The merely 'read' station tends to become neglected.

7. The operation and maintenance of automatic water level recorders by persons other than trained Staff Hydrographers has proved most unsatisfactory. Chart records have been found to be incomplete, and operation has been incorrect as to time and gauge height setting, the general standard of the records sometimes very poor. For staff operation, which will more than justify its cost, instruments requiring attention only three or four times each year should be used.

Instruments and Equipment

8. There are various types of instruments which will produce a decipherable record of water levels. The two types normally used are those which produce a graphical record of water level and those which produce a record in the form of a punched tape. The latter are in an early stage of development and apart from the fact that they do not provide a visible, easily checked record of gauge heights, they are not suitable without the provision of translators and computers. This type of instrument is more complicated to operate than a common graphic type. The most universal and satisfactory recorder in use is the simple graphical type. This produces a line representing stream levels in relation to time. The behaviour of the river, and of the recorder, is directly visible. A record of levels is produced that can be treated to obtain flows either by arithmetrical calculation or by the use of a discharge integrating instrument.

9. Recorders can be of the long period, monthly or weekly type. One long period and satisfactory type of graphic instrument, driven by a weight or special "Negator" spring, gives operation periods up to six months. Weekly and monthly spring or electric driven recorders are not recommended unless they can be serviced regularly by trained staff.

10. There are three general methods of recording water levels in graphical form; these are: (a) float and wire, (b) pressure, and (c) gas back-pressure. Of these, the float type of instrument is the most commonly used and gives the most accurate and reliable results. It is usually operated in a well connected to the stream by a pipe in such a way that the float will react to the changes in stream level. The float movement is then transmitted by the wire to a stylus that marks on a chart. Its advantage is that it is simple, easily maintained, and gives an open scale. The cost of the float well may however, be high. An instrument, the 'Surface Detector', suitable for the operation of a float in an inclined pipe actuates a standard float type of recorder, producing a standard levelgraph. It is operated electrically by batteries, and therefore presents some problems of operation and maintenance.

11. The pressure type is operated by a pressure cell located in the stream, varying pressures due to rise and fall of the stream being conveyed by a tube to the recorder where a pressure diaphram operates a recording arm that records the pressure or water level variations on a chart. Its advantages are, low cost of installation and that the instrument can be placed at any convenient point on the stream bank and connected to the pressure diaphram by a small tube. Its disadvantages are its limited gauge height scale and its inherent inaccuracy due to the necessary amplification through levers of the small movement due to pressure change.

12. The back-pressure type relies for its operation upon the pressure exerted by the head of water in the stream on gas bubbling at a uniform rate from a small nozzle located in the stream. This pressure is transferred back to the instrument through the small supply tube, and by using either a pressure cell or a manometer, the variations in pressure can be converted into gauge heights on a chart. As with the pressure type of recorder, the back pressure type is cheap to instal but, except where the expensive manometer type is used, the gauge scale is limited. Maintenance is important as gas leaks will put it out of commission.

Instrument Housing

13. In bad climatic conditions, where snow, heavy rain or extreme cold is encountered, the housing of the recorder should be lined and extensive enough to provide accommodation for the officer servicing the instrument; under moderate conditions sufficient to allow the officer to service the instrument under shelter, and in some instances lined. Suitable for mild climates where rain is not frequent or severe, shelters that accommodate the instrument only, may be of a round corrugated iron type, made to fit directly over the well, or a steel hinged top type which, when open for servicing, will provide some cover for the instrument. (See Figures I - IV).

Measurement of Discharge

14. It is accuracy of measurements of the discharge of a stream that determines the worth of the basic stream flow data. If it be not of high degree money and time spent on accurate recording of water levels and the other work involved will be completely wasted. The four methods commonly used to determine discharge are weirs, floats, slope measurement and current meter. Weirs, suitably calibrated are satisfactory; as their characteristics are well known, however, it is not proposed to deal with them here.

Floats

15. Floats can be used to estimate the velocity of a stream but should be regarded only as a secondary method of measuring discharge. They are used when more accurate methods are not possible, usually during floods. There are two requirements: a knowledge of the relationship between the velocity of the float and mean velocity, and a surveyed stretch of river giving cross-sections at regular intervals. The main difficulty is in determining the relationship between float velocity and mean velocity; this results in float discharge measurements being only approximate

Slope Measurements

16. Slope measurements can also be used to measure the approximate discharge of flood flows. A stretch of river is selected and cross-sections surveyed at various points. The slope of the water is measured, and Manning's formula, $V = \frac{1.486 s^{\frac{1}{2}} r^{2/3}}{n}$, is used where n = Manning co-efficient, s= slope of water, and r = hydraulic radius, in feet. The velocity is applied to the mean cross-sectional area of the stream. The co-efficient "n" is determined by measuring the flows at lower stages by a more positive means and applying an estimated value to the flood slope and section.

Current Meter Measurements

17. The normal method of stream gauging is the use of a current meter and will be treated in some detail. Basically, current meter discharge measurements are produced by measuring the velocity of the water with a current meter and applying that velocity to the measured area of the stream, e.g. in British units the product of velocity in feet per second by area in square feet results in the rate of flow in cubic feet per second units, (cusecs). The flow in cusecs at a point is therefore the volume of water in cubic feet passing the particular point every second. The distribution of velocity in a stream is such that it is necessary to measure the velocity in a large number of positions in the cross-section. Variations in depth across the section require water depthing at regular intervals to give an accurate measure of the area. The use of the current meter to measure velocity, consists in positioning the meter at the particular point in the section, and determining the rate of rotation of its moving wheel or propeller by timing a number of revolutions with a stop watch. From the calibration of the meter the relevant velocity can be determined.

18. Five methods of making these velocity and depth measurements can be used: wading, cableways, travelling pulley, bridge, and boats.

19. Wading. Where the depth and velocity of a stream are such that an observer can wade conveniently and make accurate measurements. It is normal for the observer to wade across the section, measuring depths and velocities at the various points. A marked cross line, usually $\frac{3}{8}$" circumference flexible wire rope, is used to locate the measuring sections and at the same time to support the observer, if necessary, against the current.

20. Cableway. Where a stream is not suitable for wading, a cage and cableway to carry the observers across the stream in the making of the necessary observations, may be used. Normal practice is to have the current meter weighted with a lead weight and supported from a hand winch by a two conductor meter cable. The meter is in turn supported

in the direction of the stream by a stayline running on a cross line upstream of the main cable. Using the main cable as a distance marker, the cage is moved to the section required and the meter positioned in the section by means of the winch, wire and stayline. Meter revolution signals are transmitted to the cage via the meter wire where they are timed and the data recorded. This is a relatively accurate method because: (a) the best measuring site within the vicinity of the gauge can be chosen and eddies, interference from piers, and logs avoided ; (b) the observers being in the cage directly above the meter, better control can be exercised in positioning it in the section, and the section across the stream can be more accurately measured; and (c) depthing can be done more accurately, as the meter and weight are on a direct line down from the winch.

21. Travelling Pulley. In this method the meter, complete with its lead weight, is moved across the stream supported on a wire strung across at the section. It is normally operated from one bank using an endless flexible wire to move a travelling frame carrying the meter along the cross wire. From the bank the meter and weight are raised or lowered by means of a two conductor meter cable, running through a pulley attached to the travelling frame. Positioning across the section is accomplished using the endless flexible wire, fitted with metal distance markers. This method is not recommended for accurate work. Depthing and meter positioning at a distance and the lack of a meter staywire tend to introduce errors. However, it is useful on small streams which are too deep to wade but too narrow to warrant a cableway.

22. Bridges. The use of bridges is limited for two reasons; they are not always at the site where measurements are required, and the conditions at bridge sites are often unsuitable for flow measurements. However, where a bridge is in the vicinity of the gauge and flow conditions are satisfactory, it can be a convenient and economical means of making discharge measurements. Two common methods used to support the meter and weight from a bridge are by a portable hand winch crane, and by a Land Rover crane. Where large bridge piers or debris interfere with the flow, use is made of a cross line strung a short distance from the bridge..From certain types of low level bridges, a rod (1 in diameter) can be used to support the meter. Very accurate results can be obtained in this way, particularly in canals. (Cranes are shown in Figures V and VI).

23. Boats. Where wide streams of moderate velocity are to be measured, boats can be used with considerable success, provided satisfactory arrangements are made to position the boat and handle the meter. In certain circumstances, anchoring of the boat can be carried out satisfactorily but additional work is required to calculate its position in the section.

Selection of Site

24. The desirable features of sites for making discharge measurements vary, depending on the type of measurement. For measurements using suspension methods, the main requirements are: measurable velocities at all ranges of flows (floods excepted), velocities reasonably steady and normal to measuring section, flow contained within one section, bed of stream reasonably even, site accessible to as high a flow as possible, and close to gauge. The downstream end of a pool usually provides a good site, for, as the flow decreases the velocities are maintained over the shallow section, whilst at higher flows the section generally becomes drowned out, resulting in velocities

keeping within reasonable limits. For wading measurements the site is usually selected by the hydrographer, as at low flows it is necessary to select one which suits the particular flow conditions. Sites which are very shallow or which have velocities below 0.5 ft per second should be avoided.

Measurement of Area and Velocity

25. Area measurements are usually made in conjunction with the velocity measurements as follows: velocity in the cross-section varies both in a horizontal and in a vertical direction, whilst the depth also varies across the section. It is necessary to divide the stream into a number of small sections and to make measurements of depth and velocities in each. The number of vertical sections to be adopted depends on conditions at the measuring site. A guide to the spacing of vertical sections is:

Stream Width (ft)	30' - 100'	100' - 150'	over 150'
Width of Vertical Section (ft)	5'	7' - 10'	10' - 20'

In all cases the first and last sections are taken as close as possible to the bank.

26. Where permanent facilities exist for suspending the meter, e.g. cableways, the depths across the section may be established either by levelling or by accurate depthing at low flow. These established depths, related to a gauge at the gauging site, serve as a check on depths obtained during a measurement and provide depths when accurate depthing is not possible.

27. For normal stream gauging work, sufficient observations are made in each vertical section to enable a curve of velocity against depth to be drawn. From this curve the mean velocity in the vertical section can be obtained by dividing the area under the curve by the depth. The number of velocity observations required in each vertical section varies with the depth; the following rules generally apply:

Depth of Water (ft)	0 - 1	1 - 3	3 - 6	over 6
No. of Velocity Measurements	1 - 2	3 - 4	4 - 5	6 - 10

Although this method takes somewhat longer than others, it is justified by its greater accuracy.

28. Sometimes it is not possible to carry out the full velocity method, owing to lack of time, rapidly rising or falling stage and the impossibility of getting the meter down to the stream bed. Under conditions such as these, measurements of velocity are made at 2/10 and 8/10 the depth, and the mean of the two readings is taken as the section mean. This assumption is based on the fact that vertical velocity curves approach a parabolic shape.

29. When it is not possible to get down to 8/10 depth, for example during floods, measurements of velocity are made at 2/10 of the depth. A correction factor, usually about 85% is applied to the 2/10 flow; 2/10 depth measurements are preferred to "surface" measurements, although "surface" measurements are usually taken at a depth of one foot. It has been found that during high flows, waves often make it difficult to keep the meter in the water at "one foot". Apart from the fact that 2/10 is a definite proportion of the depth, the meter is usually deep enough to remain under the surface. In depths of less than one foot, observations at 6/10th the depth, give

an approximate mean velocity.

INSTRUMENTS AND EQUIPMENT FOR CURRENT METER DISCHARGE MEASUREMENTS

Current Meters

30. The current meter is the instrument used to determine the velocity of the stream. Although types of meters, have been developed which indicate velocity directly, mostly electronic, the usual meter is of the inferential type, i.e. velocity is determined from the rate of turning (or angular velocity) of the moving part, when the meter is immersed in the moving water, the rate of rotation of the moving part being calibrated against the velocity.

31. The usual calibration method is to tow the meter through still water at a known velcoity, and at the same time register the revolutions per second of the meter. This procedure is repeated for a number of different velocities to enable a relationship between revolutions per second of the meter and velocity to be established. This relationship can be derived either by drawing an average line through the calibration points, or by calculating the best equation by the method of least squares. A current meter should, be reliable in its operation, light, robust and easy to handle, maintain its calibration under various conditions, and suitable for the measurement of velocities over a wide range.

32. The two principal types of current meters in common use are the cup or bucket wheel and the propeller. The cup type meter consists of a number of cups mounted on a vertical shaft. Electrical contacts for revolution counting are located in a chamber fixed to the yoke of the meter at the top of the wheel shaft. Two contacts in the chamber allow for the registration of either single revolutions or every fifth revolution of the wheel. The propeller meter is one which can be recommended for all classes of water velocity measurements; it will resolve oblique currents. Various types of propellers can be fitted to suit velocity and conditions encountered. One firm provides plaster casts which fit the propeller and reveal any deformation of the blades which would cause a change in calibration.

33. For the measurement of low velocities for use in streams of shallow depths, special pygmy meters have been developed which will measure accurately down to 0.2 ft per second. The propeller type is the better for these purposes.

Ancillary Equipment

34. The use of winches for handling current meters in suspension methods is very desirable. Not only do they reduce the time required to make a discharge measurement, but they also permit the use of heavier weight, up to 150 lb. The type of winch will depend on the weight to be handled. The drum should be long enough to accommodate the full length of meter wire in one layer so that the measurement of drum rotation can be used for depthing, through the use of a revolution counter.

35. As the signal indicating current meter revolutions is normally made by the making and breaking of an electric circuit, the cable on which the meter is supported must also transmit the meter signal back

to the observer. It is necessary therefore to use a two conductor meter cable, i.e. one which has insulated core wire surrounded by a steel wire. A special connector is necessary to join the cable to the steel hanger supporting meter and weight.

36. The provision of a stay line to support the meter is of great assistance in keeping the meter in the section and in preventing meter surging and side-sway. The stay line has been found to operate easily and simply when attached to a free running pulley on a cross line erected some distance upstream of the measuring section.

37. Cableways can be double or single wire, depending upon the span. Up to 150 ft span single wire cableways are generally satisfactory, but for larger spans double wire cableways have advantages, such as greater stability, reduced sag and better distribution of meter loads, whilst the smaller size cable required can be handled and transported to the site more easily. Cableways should be designed and regularly tested in accordance with their particular specified procedure. Type of construction depends on the site. Rock bolt anchors, tree supports, frame supports and steel pole supports can be utilized. (See Figures VII and VIII).

DISCHARGE MEASUREMENT COMPUTATION PROCEDURES

38. Arithmetical Method. The basic assumptions of the method are that the mean velocity varies as a straight line between vertical sections in the stream, and the bed of the stream is a straight line between the vertical sections. There are two ways of applying it; the "mean"section method, and the "mid" section method. The mean section method consists of dividing the stream into a number of small sections by means of spaced vertical sections. The distances between the vertical sections are measured and the mean velocity in the vertical sections obtained. Each small section is then treated by halving the sum of its two end vertical section depths and multiplying by the width between vertical sections. this gives the area of the section. Mean velocity in the section is obtained by halving the sum of the mean velocities in the two verticals. The product of the mean flow and the area gives the discharge in the small section. The flow through each small section is then summed to give the total flow. The "mid" section method differs from the "mean" section in that observations of depth and velocity are used without averaging. They are made in the same manner and in the same vertical sections as the "mean"velocity method, but the values of depth and velocity at each vertical section are applied to a cross-sectional area whose width extends halfway to the preceding and following vertical sections. This method therefore eliminates the process of averaging depth and velocities in each section.

39. Summation Curve or Integration Method. The true value of a discharge through a section is found by integrating the flow through vertical sections of unit width. In the measurement of a stream this is accomplished by using the data obtained in the arithmetical method but the mean velocity in each vertical section is multiplied by its depth to give the discharge through a section of unit width. These values in ft per second units, are plotted vertically with horizontal spacings equal to the distances between the vertical sections. The area under the curve joining these values gives the total discharge.

40. Discharge Rating Curve and Table. The discharge rating curve.

which provides the relationship between stream water level and discharge, is one of the important factors governing the accuracy of flow records. It is essential that sufficient measurements be made at various discharges to obtain a reliable curve. Discharge measurements should be made at regular intervals of time to check the validity of the curve

41. Reduction of Flows. Automatic water level recorder charts can be treated arithmetically or by the use of a discharge integrator. When chart river levels are treated arithmetically it is usual to select sufficient readings from the chart to give the mean for the day. The mean is obtained by averaging the rating table flow value for each selected gauge height and not by averaging gauge heights. A mechanical integrating instrument similar in principle to a planimeter can be used with certain strip charts to give the mean flow for the day. By setting the instrument to the rating table values, and following the river level curve on the chart, mean value for the day can be read directly from the instrument.

42. Mean flow for the day at daily read stations is generally assumed to be the discharge equivalent for the gauge heights read. If more than one reading is made, the mean of the flow values should be taken. During floods many readings should be made and hydrographs plotted. From these the mean discharge for the day can be determined

43. Presentation of Flows. Daily flow tabulations are usually required. For hydro-electric system operation studies daily flows are necessary for computer calculations. Monthly flows should be tabulated in the form of maximum, minimum, mean and total for the month. Mean yearly discharges should also be tabulated. However, calendar year divisions do not always suit the climatic conditions of the site. To obtain a yearly period where run-off during one period does not affect the other, it is often necessary to create an artificial year, termed the "Water Year".

ANALYSIS OF RECORDS

44. Apart from the detailed analysis of records required for specific projects, there are a number of analyses that add to the value of the presentation of flow data. Hydrographs of daily flows are useful for determining the time elements of flood crests and flood maximization and for the checking of the water level recording instrument. The general plotting of these graphs is not recommended.

45. A mass curve is the summation of the hydrograph. The abscissae are in units of time and the ordinate at any point represents the total volume of flow up to that point. It enables a rapid analysis of the behaviour of the stream to be made, averages over various periods to be compared and trends to be noted, and provides information on the amount of storage required to maintain various flows. The residual mass curve is the most convenient graphical presentation. It is obtained by the plotting of the accumulated departures of flow during periods from the average flow for the total period of the curve.

46. Duration curves, which show the percentage of time the flow was equal to, or greater than, a certain value, can be calculated from daily flows. The curve can also be in the form of a percentage of the average flow.

47. The double mass curve consists basically of the plot of two hydrologic elements such as rainfall and stream flow, rainfall and rainfall, or stream flow and stream flow, in such a way that the summation value on one ordinate of one element for a period of time, e.g. a year, over a number of periods, corresponds to the summation element on the other ordinate. The result of the plot is generally a straight line of uniform slope. If one element is known to be reliable, a change in slope indicates an inconsistency in the other element and investigation of the inconsistent element may be justified. The double mass curve should be used to indicate possible inconsistency in records and not as an instrument of correction.

DISSEMINATION AND PRESERVATION OF STREAM FLOW RECORDS

48. Not only should the records of stream flows be made available generally; their availability should be made known. This can be done by regular publications of stream flow records and by the circulation of annual reports to interested bodies.

49. The value of run-off records obtained today, lies mainly in the future. It is the records themselves must be carefully preserved, and so also must the evidence on which they are founded for it is by this that the authenticity of the records can be established at any time. The longer the period of records the better will be the assessment of the country's water resources.

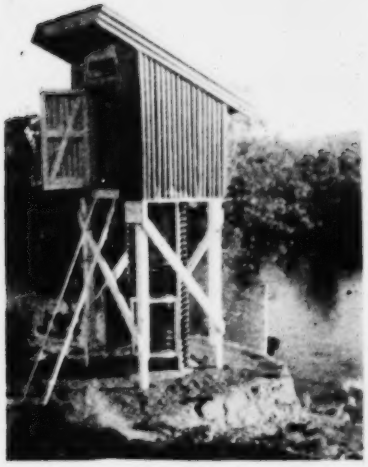

Fig. 1. Shed Type Recorder House Shelter.

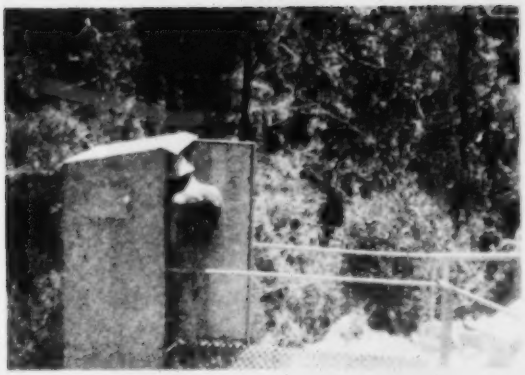

Fig. 2. Galvanized Flat Iron Shelter.

Fig. 3. Corrugated Iron Shelter.

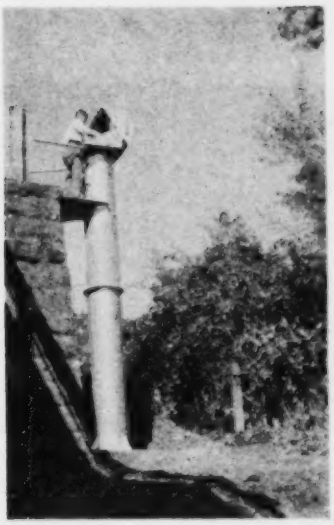

Fig. 4. Steel Hinged Top Shelter.

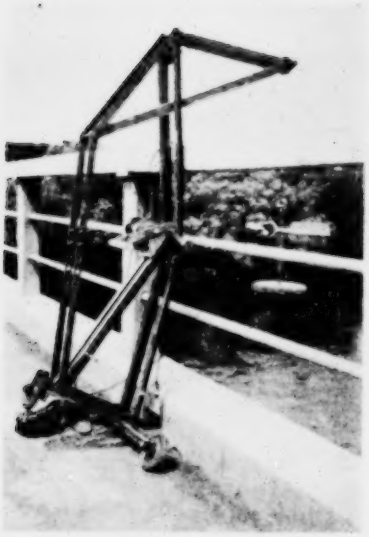

Fig. 5. Portable Bridge Crane.

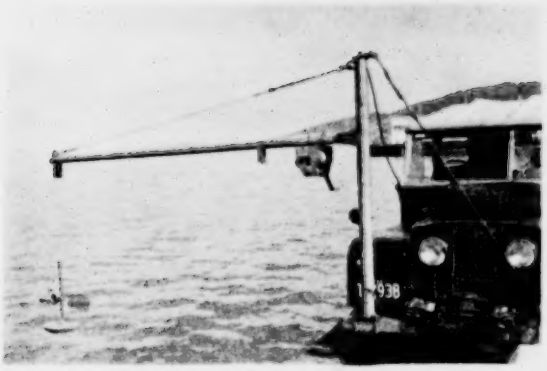

Fig. 6. Land Rover Bridge Crane.

Fig. 7. Double Cableway.

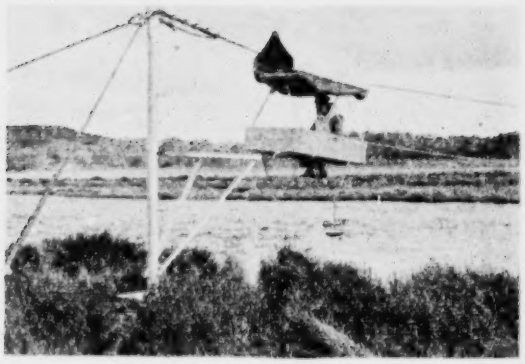

Fig. 8. Single Cableway.

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